CHAPTER 2

USE AND CARE OF LEVEL

INTRODUCTION

The level is a precision instrument used in surveying to determine and establish elevations of points and differences in elevation between points. There are many types of leveling devices used for this purpose and there are many methods and procedures which can be used to establish elevations.

In highway surveying leveling is carried out to provide the necessary vertical control to construct a highway or a bridge. A point of vertical control is known as an elevation. Sometimes in paving or in roadwork an elevation is referred to as a grade.

All elevations are related to some reference. Generally, this reference is sea-level so that a point having an elevation of 722.95 feet means that the particular point is 722.95 feet above the same reference, the same sea-level. Remember, leveling has to do with vertical control during construction.

Differential leveling is the operation of determining the elevations of points some distance apart. This is the method used in highway surveying to establish the necessary vertical control for construction. Usually, this is accomplished by direct leveling. Differential leveling requires a series of set-ups of the instrument along the general route and for each set-up a rod-reading back to the point of known elevation and then forward to a point of unknown elevation is taken. At this point some definitions are in order.

BENCH MARK

A benchmark (b.m.) is a definite point on a permanent, object which has a known elevation and a known location. Temporary benchmarks, (T.B.M.) are used many times to supplement permanent benchmarks. The elevation of a location of these points is also known but are not meant to be permanent or lasting. A benchmark is a point of reference which is convenient for leveling in a given locality. The relation to sea-level is brought to the job. Elevations of benchmarks are established by differential leveling which is very precise and obtained by running a level circuit such that the elevation of the beginning and the end of the circuit are known and tied together.

TURNING POINT A turning point (T.P.) is an intermediate point between benchmarks which provide a very temporary point of known elevation which allows the running of a level circuit between two benchmarks which are quite a distance apart. A turning point may be an iron pin which is carried by the rodman and driven firmly into the ground at a convenient location and on which rod readings are taken before an instrument is advanced and again as the initial rod readings are taken before the instrument has been re-established ahead on the circuit. After the second reading, the pin is pulled and carried ahead. turning point may be an existing convenient object upon which a rod reading can be taken, but the object has to be solid and stable and something that will not move or change in elevation for the few minutes needed between set-ups.

> Obviously, a benchmark, permanent or temporary, may be used as a turning point.

BACKSIGHT

A backsight (B.S.) is a rod reading taken an a point of known elevation, such as a benchmark or turning point. Another term for backsight is plus sight.

FORESIGHT

A foresight (F.S.) is a rod reading taken on a point for which the elevation is to be established. A foresight is sometimes called a minus sight.

HEIGHT OF INSTRUMENT

The height of instrument (H.I.) is the elevation of the.line of sight of the center of the cross-hairs in the telescope when the instrument is properly leveled. The height of instrument is equal to the elevation of the benchmark sighted plus the rod reading taken on the benchmark. In mathematical shorthand this can be written as follows:

H.I. = elevation B.M. + B.S.

A level plane of sight which is known as the height of the instrument. The important features of the telescope are its optical properties. There are four basic optical properties to consider.

- Illumination this refers to how well lighted the image appears.
- 2. Definition this has to do with sharpness of detail.

Height of Instrument (cont'd)

- 3. Width of field of view this is expressed as an angle and tells how much of the object is visible at one time.
- Magnifying power- this is the ratio of the apparent lineal dimensions of the object and of its image.

The levels used by the Indiana Department of Transportation typically are the Dumpy type level with a magnification of 26 to 30 which has an erecting eye piece so that the image sighted is seen right side up. The precision of the work done with this type of instrument is excellent to something like 200 feet.

Leveling Rod

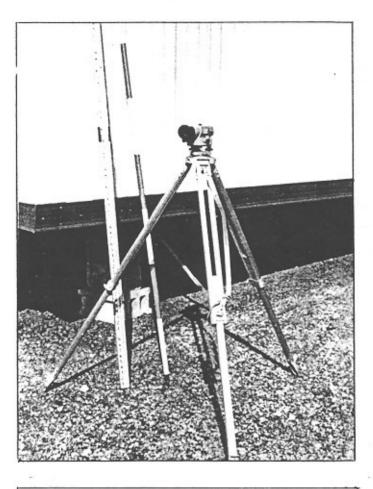
The second most important piece of equipment needed for differential leveling is the leveling rod.

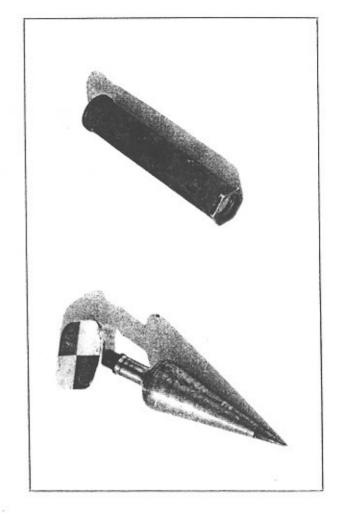
Several types of leveling rods are used in highway construction. Two types are generally preferred for highway work, the Chicago Rod and the Philadelphia Rod. The Chicago rod is a slip joint rod which has a total length of 12-1/2 feet when all sections are used. The Philadelphia rod is a sliding joint type which can extend to 15 or 16 feet. The Philadelphia is more convenient when a target is used. Selection of a rod type, and both are quite different, is either a matter of personal preference or availability.

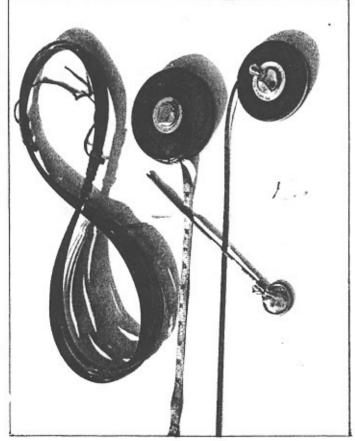
Targets

An accessory which may be used with a rod when doing more precise work is a target. The target is fitted with a built in vernier so that rod readings can be obtained to one- thousandth of a foot. Targets are rarely used for highway surveying, although they may be used when precise readings for certain bridge structures are required depending on the design of the structure or conditions which exist adjacent to the structure during construction.

Actually the level and the leveling rod are the only two pieces of equipment that a crew needs to run a precise and complete level circuit. other items of minor equipment are needed for specific types of leveling. A very handy device which is used for checking slopes and setting slope stakes is the hand level. The hand level is simply a small telescope which has a built in level bubble. The bubbles are small and therefore, are poor for precise work. Also, there is very little magnification built into the small hand level. Because all of the optical properties - illumination, magnification, definition, and width of field of view







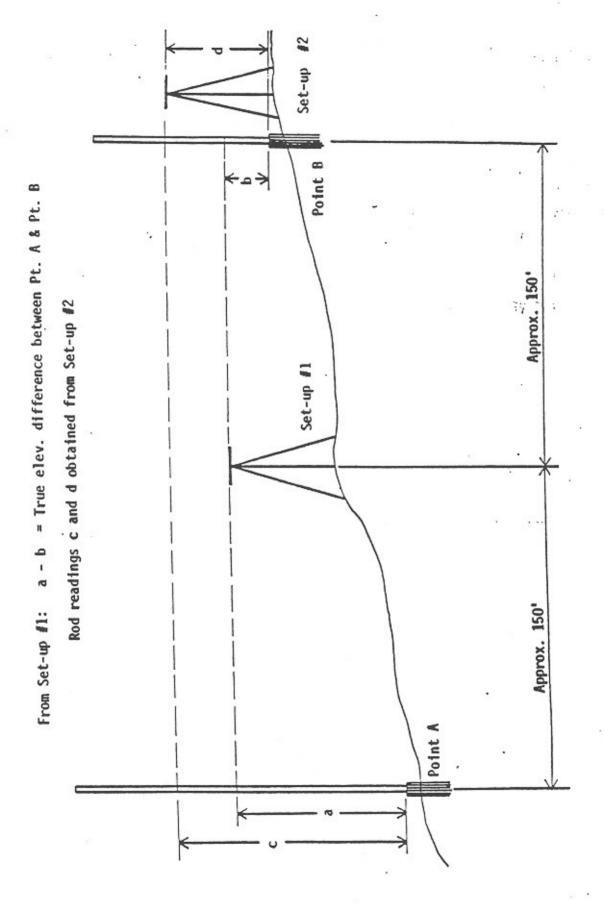


are forfeited when one uses the hand level, it is never used for precise work, but only as a convenience for short sightings or approximate sightings accurate only to the nearest tenth of a foot.

The Two Peg Test

The two peg test is a very simple test which is used in the field to determine if the line of sight of the telescope is exactly parallel to the bubble tube. This is one of the most important properties of a level which should be checked periodically. The steps below must be followed to check this most important adjustment in a level.

- 1. Set two hubs 300 feet apart.
- 2. Set up half way between the two hubs and level the instrument properly. Figure 2-1 shows a sketch of the level properly established between the two stakes represented by points A and B. It should be noted that a location is selected so that the tops of the stakes are obviously somewhat different in elevation.
- 3. The rodman sets the rod on stake A and rocks the rod so that a precise reading can be taken of the rod on this point. The man on the instrument reads the rod, making sure that he sights the rod at the center of the cross hairs and that the level bubble is truly centered when he takes the reading. The rodman moves up to point B and sets his rod on the stake and rocks the rod as the instrument man turns the instrument to get a precise reading of the rod at point B.Once again he should make sure that the bubble level is centered when he takes his reading. This is the first set-up.
- 4. The level is then moved to the highest stake, in this case stake B, and set so that the eye piece of the level is just a few inches from the rod when the level rod is plumbed on the stake.
- 5. rod reading is taken on stake B by sighting backwards through the telescope.
- 6. The rodman takes the rod to stake A and a precise reading is taken on stake A.
- 7. The true difference in elevation between point A and B is computed from the two readings obtained from the first set up.



THE TWO PEG TEST

Figure 2

Figure 2 - 1 THE TWO PEG TEST 2 - 6

THE TWO PEG TEST (cont'd) 8. The elevation difference of the second set up is computed. If the plane of sight is truly horizontal, the elevation difference of the second set up will be equal to the true difference in elevation. If this is not so, if the line of sight is not parallel to the bubble tube on the telescope, an adjustment to the instrument will be necessary. Adjustments vary from instrument to instrument and the proper procedure is different for a transit and the level. If it is felt that an adjustment of this nature is necessary, it is advisable to check with the project engineer or the district.

LEVEL NOTES

There are two forms of field notes commonly used for maintaining level circuit information. THESE ARE REFERRED TO AS THE OPEN NOTE FORM AND THE CLOSED NOTE FORM. The open note form is merely an expanded notation. A typical set of open form level notes is shown in Figure 2-2. It is already noted that each set up, noted by HI, has a corresponding backsight and produces an H.I. while each turning point, noted by T.P., is defined by a foresight and an elevation. The numbers used in the open note form of figure 2-2 are shown in figure 2-3 which shows an example of differential leveling, and traces the work done to get from the benchmark A to benchmark K. The elevation of benchmark A is given at 820.00. The level is set up at the location marked I and the rod reading on benchmark A is 8.42. This rod reading is called the backsight or the plus sight, which is abbreviated as B.S. or (+). Remember, the backsight is a rod reading taken on the A point whose elevation is known and used to determine the height of instrument. For the example shown, the H.I. equals the elevation of benchmark A plus the backsight reading.

H. I. = 820.00 + 8.42 = 828.42
This is recorded in the H.I. column of notes as the H.I. of set up number one. After the rod reading on A has been taken, T.P. #1 - turning point number one - is selected so that distance from benchmark A to the instrument is approximately equal to the distance from benchmark A to the instrument to T.P. #1. A rod reading is then taken on the turning point and is called a foresight reading, which is noted as F.S or (-). The turning point is a conveniently located temporary benchmark so that the instrument may be moved ahead and a sight taken back on this point to provide a point of vertical reference. The rodman remains at the first turning point while the level is moved to set up number two. A backsight reading is taken on the rod held at

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Figure 2 - 2 TYPICAL LEVEL NOTES: OPEN FORM

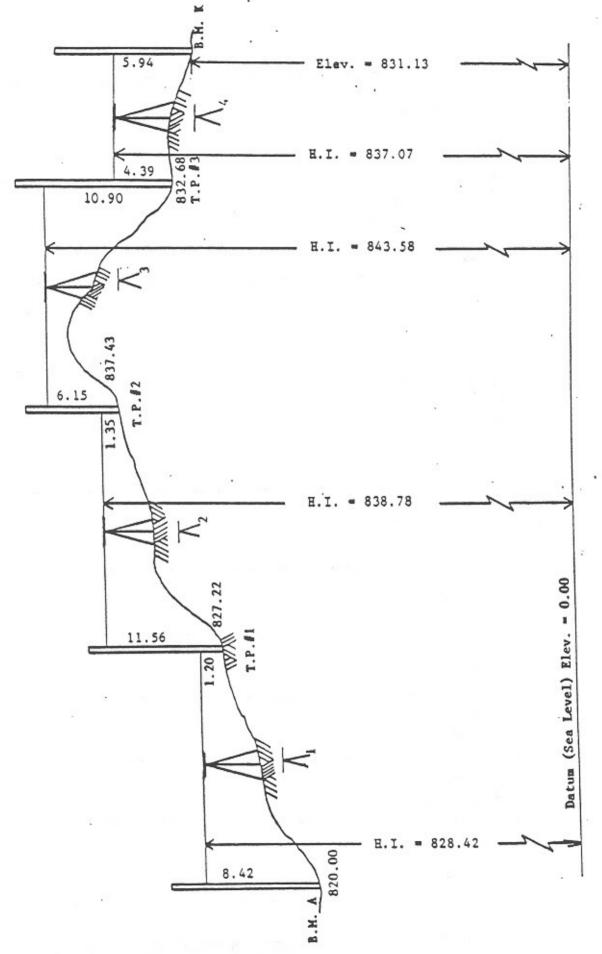


Figure 2 - 3 EXAMPLE OF DIRRERENTIAL LEVELING

2 (

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Info	~	end of culvert ot of Sta. 116 + 78.		
	Boat spike in 30" Oak tree, 186 ft. right of Sta. 106 + 43.	Bronze Marker on N. end of culvert headwall, 56 ft. right of Sta. 116 + 78.		
B.M. Elev.	820.00	831.15 k		
Elev.	827.22	832.08 831.13 831.15 Check		
F.S. (-)	1.20	5.94		
LEVEL CIRCUIT H.1. F.S. (-)	828.42 838.78 843.58	837.07	2	
B.S. (+)	8.42 11.56 6.15	4.39		
STATION		T.P. #3 B.H. K		

Figure 2 - 4 TYPICAL LEVEL NOTES: CLOSED FORM

Level Notes (cont'd)

turning point number one and the rod is moved to turning point number two for a foresight reading at another conveniently located point ahead on rod reading can be obtained on benchmark K. In the example shown in figure 2-3 there are four set ups and three turning points or intermediate temporary benchmarks. Using the same numbers and the same example a set of closed form level notes can be developed as shown in figure 2-4. It is readily seen that the closed form eliminates the set up line and doubles the information noted for each turning point.

Level Set-Up Procedure

The first step in setting up the level is to attach the level itself to the tripod or legs. The level should be placed in a location which is fairly open so that a clear rod reading can be obtained on the benchmark. The proper setting of the tripod is very important. The legs of the tripod must be spread so that the base plate of the level is approximately horizontal and provide a stable base for the level itself. If the ground has a steep slope, two of the legs should be set about the same elevation and lower on the slope than the third leg. Make sure that the legs are set firmly into the ground then tighten the three wing nuts of the legs just under the head. Avoid setting the tripod on a hard slick surface such as a bituminous or concrete pavement or sidewalk unless absolutely necessary.

Figure 2-5 shows an engineer's Dumpy level. This level is still used by some Engineers/Supervisors with INDOT. The base plate which attaches to the tripod is shown as item # 1. Item or part #2 are the leveling screws which are used in pairs to center the bubble in the tube below the telescope when the telescope or sighting tube is aligned over a pair of leveling screws. To center the bubble in the tube below the telescope when the telescope or sighting tube is aligned over a pair of leveling screws. To center the bubble, first loosen all four leveling screws uniformly and turn the telescope so that two leveling screws are directly under the telescope, and the telescope is in line with the first sight to be taken. With telescope directly over a pair of leveling screws, bring the bubble to the center of the tube by loosening one screw while tightening the other with the thumb and first finger of each hand. The bubble will move in the same direction as the left thumb. When the bubble becomes centered in the tube, make sure that the pair of leveling screws are snug- DO NOT over tighten. Now rotate the telescope 90 degrees in either direction.

Leveling Screw Bubble Level 4.3.5

Bubble Level Adjusting Screw Horizontal Motion Tangent Screw Cross Wire Ring Adjusting Screw Eye Piece Horizontal Motion Clamp Focusing Screw Base Plate

Figure 2 DUMPY LEVEL

Level Set-Up (cont'd)

so that the telescope is directly over the other pair of leveling screws and repeat the process to bring the bubble to the center of the tube. Now turn the telescope back 90 degrees so that it is over the original pair of leveling screws and check the bubble to make sure that it is centered. If the bubble is no longer centered, then "touch up" the leveling screws to bring it to center and rotate the telescope back over the other pair of leveling screws to check the bubble again. If the instrument is in fairly decent adjustment, the bubble should remain centered.

When the set up is completed, the instrument man is now ready to take his or her initial shot or backsight on the benchmarks or turning point which is the starting point and point of known elevation for a level circuit. He or she rotates the telescope so that they are sighting directly at the benchmark. The rodman takes the rod and makes sure the bottom of the rod is clean, then sets the rod on the benchmark. It is the rodman's responsibility to make sure that the rod is clean, that sections of the rod are together properly, and that, of course, he is holding the rod right side up. The face of the rod, of course, must be facing the instrument. The rodman stands directly behind the rod with both hands on the sides of the rod so that his fingers are not covering the face of the rod. By standing directly behind the rod, the rodman makes sure that the leveling rod is plumb. Now as the man on the level sights through the instrument at the rod, the rodman begins to rock the rod toward the instrument and back to himself so that he is moving the rod forward approximately 9 inches and then directly away from the instrument the same amount. A slow, uniform rocking motion is applied by the rodman.

As the instrument man sights through the level, he will se the cross hairs in his field of view. He turns the level so that the center of the cross-hairs are directly on the rod. He will see the f ace of rod move up and down as the rodman rocks the rod. The numbers on the rod will increase and then decrease to some minimum number then increase again and continue increasing and decreasing as long as the rodman continues to rock the The minimum number on the rod cut by the horizontal cross hair is the rod reading on the benchmark. The instrument man should take the reading, keep it in mind, then look to check the condition of the bubble in the bubble tube to make sure that it is exactly centered, if it is not, he can "touch up" by adjusting the appropriate leveling screw. He then sights through the telescope again and takes another

Level Set-Up
(cont'd)

reading and records this reading as the backsight. get a clear picture of the rod through the telescope, items #7 and #5 as shown in figure 2-5 are used to provide two adjustments that will bring the rod into sharp focus, bring the cross hairs into sharp focus, and eliminate parallax. Parallax results when the optics are out of adjustment. The presence of parallax can be determined by nodding the head up and down while looking through the telescope. There should be no movement of the image relative to the cross hairs. Movement indicates parallax is presented and adjustment is needed. Items #3 and #9 provide a clamp and fine adjustment so that the telescope can be locked onto a point. Item #3 is the horizontal motion clamp which locks the telescope. Item #9 is the horizontal motion tangent screw which provides the fine adjustment so that the telescope be turned a degree or so in either direction from the locked position by turning the knurled knob.

The rod reading on the benchmark or turning point is recorded in notes and when added to the elevation of the benchmark gives the elevation of the height of instrument, H.1, which is the elevation of the plane, the center of the telescope. The rodman moves ahead to the next point to be established, places the rod on the surface whose elevation is required and begins to rock the rod as he did on the benchmark. The instrument man rotates the telescope so that he is sighting the rod with the center of his cross hairs then takes a reading. Since the elevation of the cross hairs is known, the rod reading on this point is subtracted from the H.I. and the elevation of the point will be determined.

There are three specific things to keep in mind so that the results of direct differential leveling will be accurate, even though the instrument may be out of adjustment.

 Always center the bubble before the final reading is obtained and recorded.

Always sight the rod with the center of the cross hairs.

 Balance the backsight with the foresight, specifically, the distance from the rod to the instrument from the back and foresight, with a maximum of 200 feet.

Care and Cleaning of the Level

When the level is carried on the shoulder, the clamps should be tight enough to prevent wear, but loose enough so the level can "give" if it is accidentally bumped.

When the level is carried inside a building, outside around a dense growth or anywhere there is a chance it may be bumped, it should be carried under the arm with the instrument head in front of the carrier.

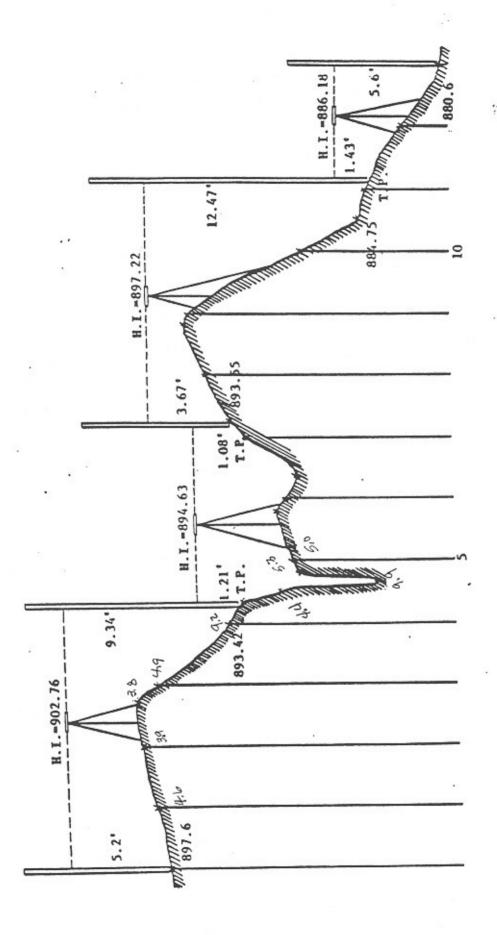
The level should be carefully set down. The cross hairs could be broken or the instrument jarred out of adjustment by harsh treatment. When being transported in a vehicle, the level should be packed in it's case and placed in a location to minimize vibration. Do not tighten the leveling screws to tight. This could cause warping of the plate. The level should never be left unguarded. The tripod legs should be spread and pushed in the ground to prevent its being knocked down. instrument should be protected from rain by a waterproof cover. If a waterproof cover is not available, the dust cap should be placed on the objective lens as soon as possible and the instrument taken inside. when brought inside, excess moisture should be wiped off the instrument immediately and allowed to thoroughly dry before it is placed in it's case. Dust should be removed with a camel hair brush, if available. The eye piece may be cleaned with alcohol and wiped with a soft cloth.

Profile Leveling

The purpose of profile leveling is to determine the elevations of the ground surface along some definite line. In INDOT work it is necessary to know the existing ground surface profile to provide sufficient and necessary information for both design and construction. Profiles are normally plotted such that the vertical scale is exaggerated in relation to the horizontal so that the differences in the elevation are accentuated.

The line along which the profile is to be taken may be marked prior to the survey. This is normally done in 100' stations. A rod reading will be taken at each full station and at each major break in ground slope. This procedure

differs from the running of a circuit level in that more foresights will be taken from each set up. The stations of the breaks in slope are taped and referenced from the full stations established along the profile line, see figure 2-6.



PROFILE LEVELING

Figure 2

Figure 2 - 6 PROFILE LEVELING 2 - 16

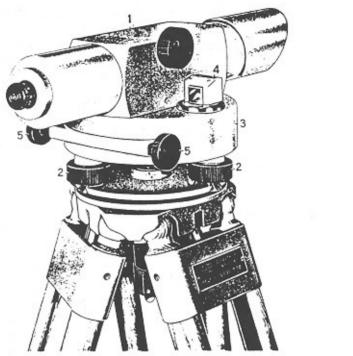
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r.s.		5.2	4.6	3.9	3.8	6.9	9.2	9.34	4.4	6.6	5.3	5.0	3.9	4:5	5.4	2.2	1.08	2.4	1.1	1.9	8.4	11.3	12.2	12.47
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Figure 2 - 7 PROFILE LEVEL NOTES

Profile Leveling (cont'd)

A sample of a set of profile field notes are shown in figure 2-7. Notice that the turning points and benchmarks are read to hundredths of a foot while the ground rod readings are read to tenths of a foot. It is a waste of time to try to obtain ground rod readings any more precise than to tenths of a foot.

LEVELING



Courtesy of Keuffel & Esser Company

- 1. Telescope 3. Head
- Leveling screws
 Viewing prism

Figure 2-8 SELF-LEVELING LEVEL

DESCRIPTION
OF SELFLEVELING
LEVEL

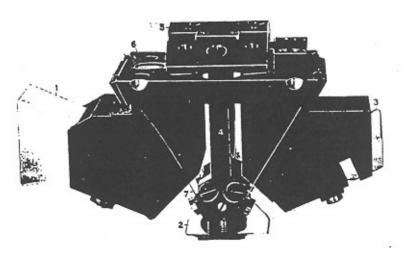
A Zeiss self-leveling level is shown in figure 2-8. The telescope (1) has the usual eyepiece system, objective lens, focusing mechanism, and reticle with cross lines. Also there are 3 leveling screws, (2), and the instrument is supported on a tripod. The head (3), which encloses the tops of the leveling screws, can be leveled by means of these screws. To enable the surveyor to determine when the head (3) is level, there is a circular level vial, which can be viewed through the prism (4). With this prism in the position shown in figure 2-8, the circular level can be viewed when the surveyor looks horizontally parallel to the axis of the telescope. The prism can be turned so that the level can be seen when the surveyor looks horizontally at the side of the telescope.

LEVELING

There is no longitudinal spirit level to show when the telescope is level. None is needed. It is only necessary to level the head (3) approximately by means of the leveling screws and the circular level. Then the line of sight is made exactly horizontal, with the telescope turned in any direction, by an automatic device called a compensator inside the telescope. Also, there is no clamp for preventing rotation of the telescope in a horizontal plane. An automatic coupling takes its place. To sight the telescope toward an object, such as a leveling rod, the telescope is rotated by hand so that it points nearly in the proper direction. Then either tangent screw is turned to make the fine adjustment.

Compensator

A compensator of the type used in a Zeiss telescope is shown in figure 2-9. Its main parts are 3 prisms 1,2, and 3. The action of these prisms is represented diagrammatically in figure 2-10, (a) to (c). The compensator is inserted in the telescope between the reticle and the focusing system, with the prism 1 toward the objective lens. The prism bends the lines of sight downward from points on the observed object. Then the prism 2 bends them so that they pass the reticle and go through the eyepiece system. At the same time this prism turns the image to its true position, so that the image is neither upside down nor reversed right for left.

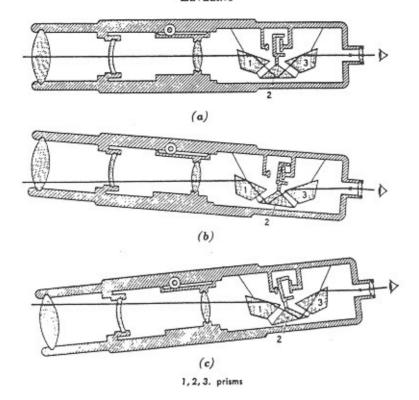


Courtesy of Keuffel & Esser Company

- 1,2,3. Prisms
 4. Vertical Member
- Weight
 Support Plate

Figure 2-9 COMPENSATOR IN SELF-LEVELING LEVEL

LEVELING



- (a) Telescope exactly level
- (b) Telescope inclined upward
- (c) Telescope inclined downwards

Figure 2-10 POSITIONS OF COMPENSATOR

As shown in figure 2-9 and as indicated in figure 2-10, the prism 2 is carried by a pendulum and is free to swing so that it automatically makes the line of sight horizontal. Of the telescope is exactly horizontal, as in figure 2-10 (a), the part of the line of sight at the eyepiece lies in the prolongation of the part passing through the objective lens. Of the telescope is tilted slightly, as in figure 2-10 (b) or (c), the part of the line of sight at the eyepiece is horizontal, but is offset from the other horizontal part.

The pendulum assembly that carries the prism 2 is constructed in the following manner: at the top of the vertical member 4, figure 2-9, is a dome shaped weight 5, which rests on the main support plate 6. This plate has a whole through which the vertical member passes. Inside the vertical member is a damping piston which moves in a damping cylinder. The movement of the pendulum is controlled by the piston and four nonmagnetic wires 7 which run from the bottom of the vertical member to the corners of the support plate.